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UNIFORMITY OF LASER-DRIVEN, ABLATIVELY ACCELERATED TARGETS.(U)

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A double-target technique is used to measure the uniformity with which laser irradiated thin foil targets are ablatively accelerated. Studies of the effects of laser nonuniformities on the target acceleration reveal an increase in smoothing (symmetrization) with increasing laser intensity. Measurements of targets accelerated to velocities (160 km/sec) sufficient for pellet fusion implosions, ~~will be~~ presented and discussed.

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# UNIFORMITY OF LASER-DRIVEN, ABLATIVELY ACCELERATED TARGETS

A high gain laser pellet implosion requires that the pellet shell be uniformly and efficiently accelerated to velocities of about 150 to 300 km/sec.[1] Experiments conducted at NRL model the early stages of the pellet implosion through studies of the ablative acceleration of laser irradiated planar targets.[2,3,4] Earlier measurements demonstrated that targets could be ablatively accelerated to velocities of 100 km/sec with efficient conversion (16%) of laser energy into target kinetic energy.[3] In this paper, we present space and time resolved measurements of the motion of ablatively accelerated targets using a novel double-target technique which has the capability of resolving the ablation pressure and velocity uniformities (about 1%) required for pellet implosions. Included are studies of the effects of nonuniformities in the focused laser profile on the target motion as a function of irradiance. Measurements of targets accelerated to velocities (160 km/sec) sufficient for fusion implosions are also presented.

Many phenomena affect the ease with which matter can be ablatively accelerated with high spatial uniformity by a laser. Nonuniformities in the incident laser beam can produce variations in the ablation pressure and mass ablation rates across an accelerated target. Efficient target acceleration requires that a large fraction of the target mass be ablated.[4] Even small nonuniformities in the mass ablation rates may then produce mass variations across a target which compound the effects of pressure nonuniformities. The requirements on the laser uniformity are relaxed somewhat by smoothing due to lateral energy flow in the blowoff plasma. Roughly, one expects incident laser nonuniformities of scalelength L to be smoothed when the separation from the laser absorption (near critical) layer to the ablation layer is larger than L. This separation is likely

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to be a function of the incident irradiance, the laser wavelength, and the target material. Other phenomena which may complicate the laser-target interaction include self-focusing of the incident laser beam in the blowoff plasma and hydrodynamic instability.

The experiments were conducted using a 1.05- μm, 4-nsec-duration (FWHM) laser beam (E <500J) focused onto thin polystyrene (CH) targets. Many diagnostic systems, described in detail elsewhere, monitor the laser-target interaction.[4] A unique aspect of the experiments discussed here involves studies of the collision of ablatively accelerated targets with a second (impact) foil to infer properties of the accelerated target. The double-target consists of 2 parallel planar thin foils separated by variable distances (100-1000 μm). Use of relatively massive impact foils (7-μ m Al) allowed us to distinguish phenomena involving the high density regions of the accelerated target. Optical shadowgraphy studies show that the second foil reacts to the collision at a time consistent with the impact time calculated from ablation pressure measurements of the laser irradiated foil.[5] Coincident with the time of impact, optical emission measurements indicate the rear of the impact foil is suddenly heated to several electron volts. Nonuniformities in the light emission associated with this impact heating can be used to determine the uniformity of the laser accelerated target. Suppose the laser irradiated target is nonuniformly accelerated across its diameter to different velocities. Those regions of the target traveling at the higher velocities will impact the second foil at an earlier time than those traveling more slowly. By making space and time resolved measurements of the emission from the rear of the second foil, differences in the impact times can be detected and thus the target's velocity uniformity determined. We conduct such measurements using an optical streak camera with the slit focused across the center of the impacted region. In the case shown in Fig. 1(a), a large amplitude nonuniformity of 140- μm width was introduced in the laser focal spot. The streak record shows a corresponding nonuniformity in the time of arrival of different sections of the accelerated foil at the impact foil location. A similar result was obtained in an earlier study employing a laser-Doppler velocimeter.[6] The double-foil technique has proven to be more sensitive than the Doppler technique, and less susceptible to preheat effects, thereby allowing studies at much higher irradiances.

We have conducted systematic studies of the effects of laser nonuniformities on the target acceleration using the double-target technique. Relatively thick foil-targets accelerated to velocities of only 30 to 50 km/sec were employed for these studies. Since only a small fraction of the target mass is ablated, velocity nonuniformities should be directly proportional to the ablation pressure nonuniformities. Figure 1(b) shows the nonuniformity of a target irradiated with the same laser profile as in Fig. 1(a), but at approximately twice the irradiance. The nonuniformity in the target velocity is markedly smaller for the higher irradiance case. The velocity nonuniformities of the accelerated targets are calculated from the difference in impact times across the irradiated portion of the target. These velocity nonuniformities, ($V_{max}/V_{min} - 1$), are plotted in Fig. 1(c) as a function of incident irradiance for several wavelength and amplitude intensity perturbations. In all cases there is a clear increase in smoothing with irradiance. This effect is probably caused by increased separations between the absorption (near critical) and ablation regions. Such increases with irradiance have been observed in computer simulations.[7] At the highest irradiance studies, $1.5 \times 10^{13}$ W/cm$^2$, 140- $\mu$m perturbations in the focused laser profile are nearly smoothed out, while 220-$\mu$m perturbations are imprinted on the target. This smoothing is consistent with the absorption-ablation separation, about 100 $\mu$m, predicted by one-dimensional analytic[8] and computational studies.[7] The experimental geometry can affect the expansive flow of ablated material which determines this separation. For planar targets this flow will be nearly one-dimensional over distances small compared to the focal spot diameter, and will diverge laterally farther away. We employed a focal diameter, 800 $\mu$m, much larger than the ablation-absorption separations encountered; this prevented such finite-spot-size effects from dominating the symmetrization.

Experiment and theory indicate that ablation pressure scales with irradiance according to the relation $P \propto I^{0.8}$.[5,9] In the absence of any lateral smoothing, this scaling would yield for thick targets

$$V_{max}/V_{min} \approx P_{max}/P_{min} \approx (I_{max}/I_{min})^{0.8}.$$

The calculated velocity nonuniformity ($V_{max}/V_{min}$ -1) using the above scaling is 0.74 for case 3 in Fig. 1, ($I_{max}/I_{min} \approx 2$, 140-$\mu$m FWHM perturbation). The measured velocity nonuniformities for this case were 0.6 at $0.3 \times 10^{13}$ W/cm$^2$ and 0.1 at $1.5 \times 10^{13}$ W/cm$^2$. At the lower irradiance the calculated and measured velocity nonuniformities are nearly equal; while at the higher irradiance the measured velocity nonuniformity is about one-seventh the calculated value, indicating there is significant lateral smoothing. If similar smoothing can be achieved for smaller amplitude perturbations in the laser intensity, then lasers with short scalelength beam nonuniformities of about 9% will be adequate to achieve the 1% ablation pressure uniformities presently required for high-gain-pellet designs.

We have also studied the acceleration of thin targets where a large fraction of the initial mass is ablated. Figure 2(a) shows a comparison of the uniformity of two different thickness targets accelerated with identical laser conditions. The thicker, 12- μm CH target is accelerated to 50 km/sec with velocity nonuniformities of less than 10%. The thinner, 3.5-μm CH target exhibits velocity nonuniformities in excess of 30%. Front surface ablation measurements indicate about 60% of the thinner target is ablated. As discussed earlier, this large ablation fraction can increase the effects of nonuniformities in the mass ablation rate. The peak rear-surface brightness temperature[2] is also much higher for the thinner target (30 eV) than the thicker target (7 eV). Increased preheat due to soft x-rays and other mechanisms discussed in reference 2, may be producing this higher temperature. However, as discussed below, higher temperatures may also be caused by break-up of the accelerated target.

Despite the uniformity and preheat complications illustrated in the above measurements, we have found parameter regimes where planar targets can be ablatively accelerated to velocities required for pellet implosions while remaining relatively cold. This involved balancing the conflicting requirements of employing targets which are thick enough to prevent excessive preheat and mass ablation, yet thin enough to reach high velocity. We also found it advantageous to minimize edge effects[4] by using a laser pulse short enough that the distance the target moved during its acceleration was small compared to the focal spot diameter.

Figure 2(b) shows measurements of 6.5-μm thick CH targets accelerated to 160 km/sec by 2.6 nsec, 400J laser pulses focused onto a 600-μm spot diameter ($I \approx 5 \times 10^{13}$ W/cm$^2$). The velocity nonuniformity ($V_{max}/V_{min} - 1$) at a time near the end of the target acceleration is about 15%. In contrast the laser profile used to obtain these results has modulations with $I_{max}/I_{min} \approx 2$. The small measured velocity nonuniformity indicates that significant symmetrization also occurs even when a large fraction (40%) of the target mass is ablated. In Fig. 2(b) the position of the target as a function of time determined by the double-foil technique is compared to that computed using measured[5] scaling laws for mass ablation rates, $\dot{m} \propto I^{0.6}$, and pressure, $P \propto I^{0.8}$. The measured and computed positions are in good agreement. The peak rear-surface brightness temperature of 10 eV occurred near the end of the laser induced target acceleration. Assuming this is representative of the interior temperatures, the ratio of target kinetic to thermal energy is about 50.

It is interesting to examine the classical Rayleigh-Taylor growth rate for the conditions of these high velocity results. For the accelerations encountered, perturbations with wavelengths near the 6.5 μm initial target thickness should exponentiate about 20 times during the laser pulse. Since the rear-surface temperature remains low, the data implies that if such short wavelength instabilities are indeed growing, they saturate short of breaking the target, which would allow hot, laser-ablated material to reach the rear surface. This apparent inhibition of short wavelength Rayleigh-Taylor instability was also observed in another study which involved measurement of mass ablation rates.[10]

To summarize, we have investigated the velocity uniformity of ablatively accelerated targets using a sensitive double-target diagnostic technique. The results are encouraging for the pellet fusion application. We observe significant symmetrization of short scalelength laser nonuniformities and a trend of increased smoothing with increased irradiance. Small diameter (0.6mm) targets were accelerated to fusion velocities despite imperfections in the laser profile. However, fusion reactor pellets are likely to have much larger diameters (about 5-10 mm). An unresolved question for further work is whether symmetrization and inhibition of hydrodynamic instability can also be achieved over scalelengths comparable to such pellet dimensions.

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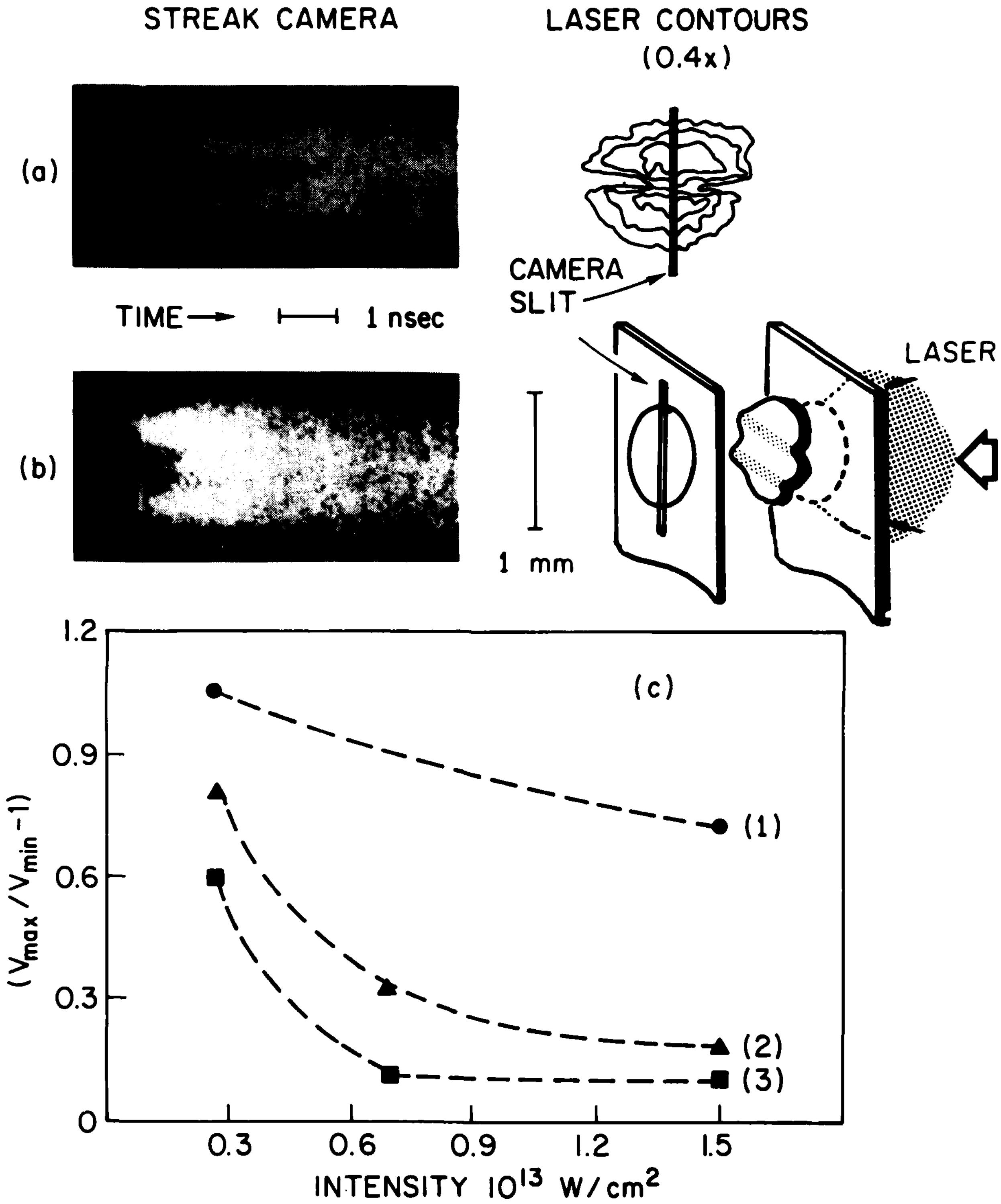
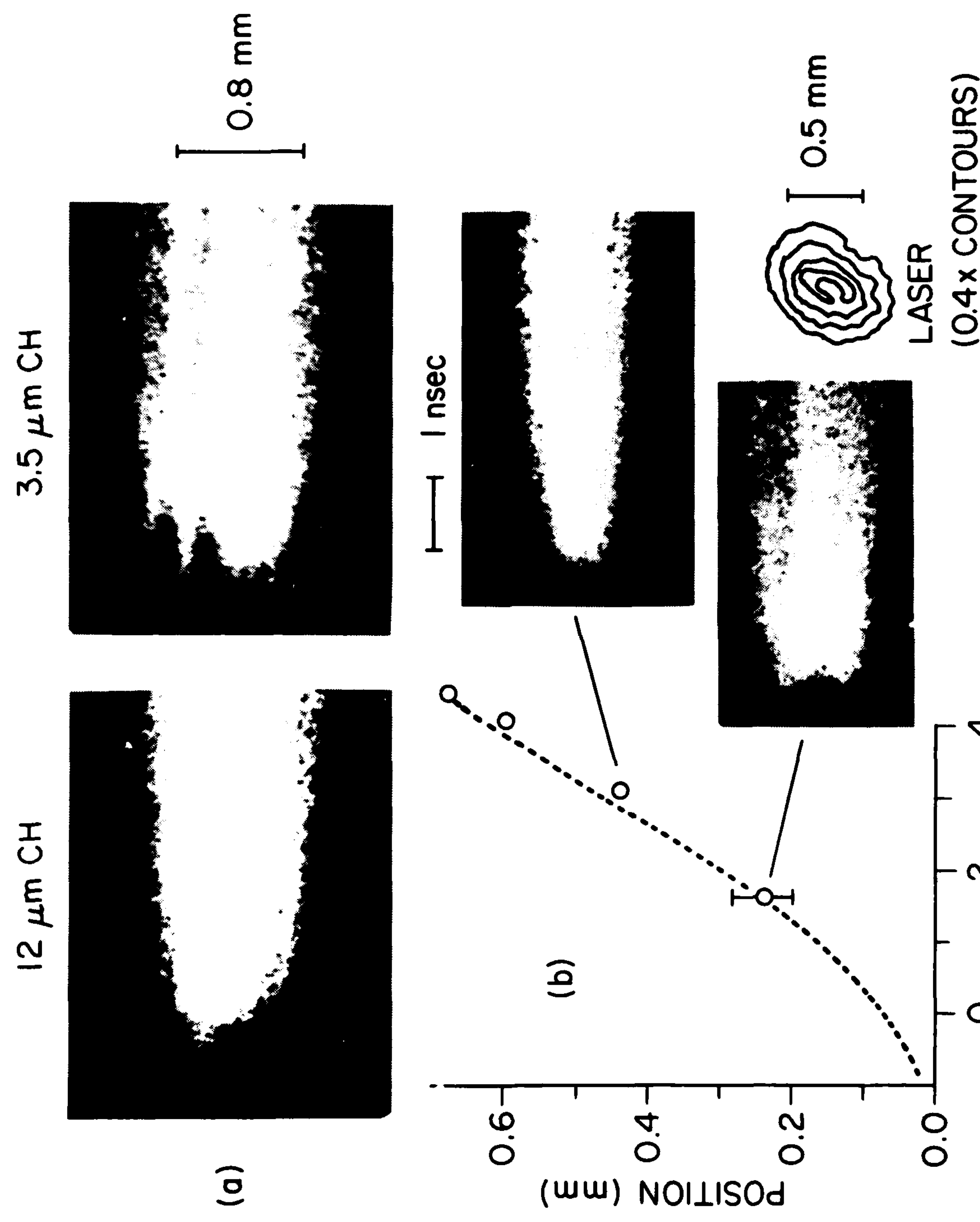



Fig. 1 — (a) and (b) Streak camera record of light emission from the rear of an impact foil struck by an accelerated target. The target is irradiated by a structured laser profile at (a) $0.7 \times 10^{13}$ W/cm$^2$ and (b) $1.5 \times 10^{13}$ W/cm$^2$. (c) Target velocity nonuniformities graphed as a function of irradiance for several perturbations (dips) in the incident beam: case (1) is with $I_{max}/I_{min} \approx 10$, 220 $\mu$m FWHM dip; (2) $I_{max}/I_{min} \approx 6$, 140-$\mu$m dip; (3) $I_{max}/I_{min} \approx 2$, 140-$\mu$m dip. Case (2) has the laser contours given in the figure. The foil spacing for the above results is 200 $\mu$m and the spatial resolution is 20 $\mu$m.



(a)
12 μm CH
3.5 μm CH
0.8 mm
1 nsec
0.5 mm
LASER
(0.4x CONTOURS)
(b)
POSITION (mm)
0.0
0.2
0.4
0.6
0
2
4
TIME (nsec)

Fig. 2 — (a) Double-foil measurements of the uniformity of two different thickness targets accelerated with the same laser conditions. (b) Double-foil position and uniformity measurements of targets ablatively accelerated to 160 km/sec. The dotted line is the calculated position, the open circles are the experimental results, and $t = 0$ is the peak of the laser pulse.

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